



PAPER • OPEN ACCESS

## Effect of Special Misorientations – Crystallographic Ordered Boundaries in Recrystallization in Aluminium Alloy of Al-Si-Mg System

To cite this article: P L Reznik *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **969** 012012

View the [article online](#) for updates and enhancements.

 <p><b>The Electrochemical Society</b> <small>Advancing solid state &amp; electrochemical science &amp; technology</small> 2021 Virtual Education</p> <p><b>Fundamentals of Electrochemistry:</b> Basic Theory and Kinetic Methods Instructed by: <b>Dr. James Noël</b> Sun, Sept 19 &amp; Mon, Sept 20 at 12h–15h ET</p> <p><b>Register early and save!</b></p>	
---	--

# Effect of Special Misorientations – Crystallographic Ordered Boundaries in Recrystallization in Aluminium Alloy of Al-Si-Mg System

P L Reznik<sup>1</sup>, A A Redikultsev<sup>1</sup> and M L Lobanov<sup>1,2</sup>

<sup>1</sup>Ural Federal University named after the first President of Russia B. N. Yeltsin, 19, Mira st., Ekaterinburg, 620002, Russia

<sup>2</sup>M. N. Mikheev Institute of Metal Physics of Ural Branch of the Russian Academy of Sciences, 18, S. Kovalevskaya st., Ekaterinburg, 620990, Russia

E-mail: p.l.reznik@urfu.ru

**Abstract.** The deformed and recrystallized states of surface regions of hot-rolled aluminium alloy plates of Al-Si-Mg system were investigated by the method of orientation microscopy (EBSD). In the deformed state mainly shear texture components were detected. In the recrystallized structure, there was a significant dispersion of deformation texture due to an increase in the proportion of components that were located at the edges of the deformation texture. It is shown that the crystallites, which are boundary a deformed matrix with the misorientation approximately corresponding to rotation axis  $\langle 552 \rangle$  at an angle of  $52.5^\circ$ , become the nuclei of recrystallization.

## 1. Introduction

Interest in texture is, among other things, related to the manifestations of anisotropy of physical properties [1], as well as plasticity, hardness and tendency to resolution of textured material [2–7]. It is more important to note that texture in a deformed material has a noticeable influence on the orientation-dependent properties of the material even after subsequent processing (deformation treatment, heat treatment) [8]. The specified features mean that texture development accounting is a tool to optimize technologies of material production [9] or to create new technologies [10].

Targeted deformation influence on metal is accompanied by texture appearance [11, 12], and also due to dislocations sliding is accompanied by deformation of all its crystallites [13]. Based on the assumption that sliding systems possess maximum tangential stresses, deformation texture development models of Sachs [14], Taylor [15] and some others [16] have been designed.

Understanding texture transformation processes during recrystallization is an important and unresolved task. The inability to predict the texture of annealing, or the degree of its scattering due to insufficient knowledge of some microstructural components [16] of the deformed state does not allow to solve the problem of predictable changes in the characteristics of the final production product.

Modern experimental methods of studying the texture state of the material (based on EBSD [16–18]) allow tracking the movement of boundaries between elements of the mesostructure during recrystallization. Thus, the possibilities to describe boundary motion at the level of sliding and dislocation sliding are opened, which leads to explanation of recrystallization processes using evolution of special boundaries.



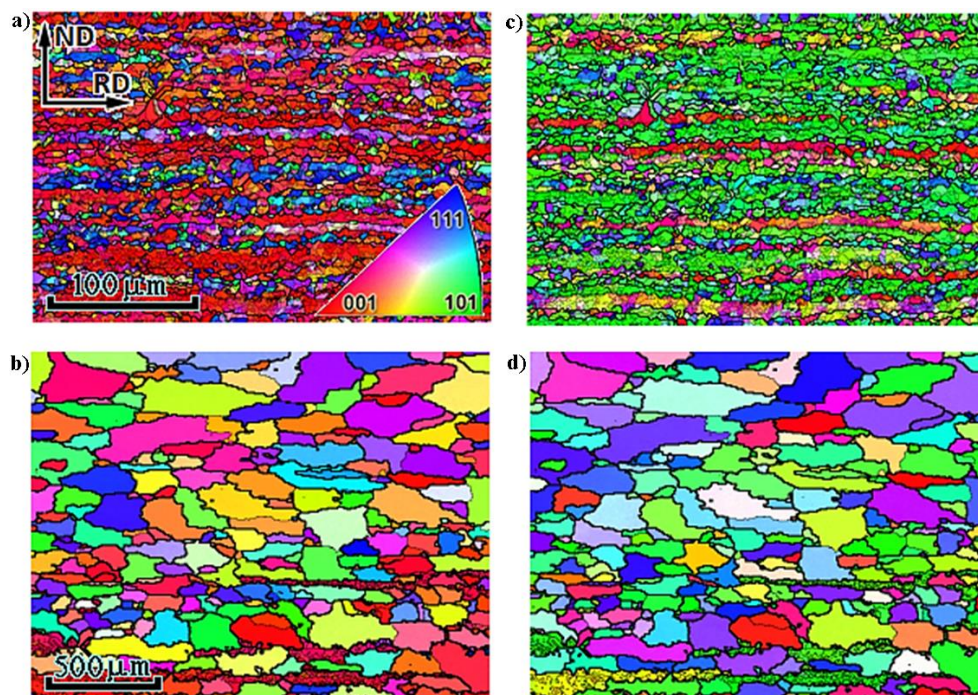
It is important to note the role of local texture. The local texture determines the structure of the boundary between two neighboring crystals, and also determines the direction of the recrystallization process (for example, macro texture of recrystallization). In this context, modern research of crystallographic aspects of nuclei “nucleation” at any recrystallization as well as correlation of deformation orientations with orientations of primary recrystallization (PR) and then PR orientations with orientations of either normal or abnormal growth come to the foreground [19–21].

Revealing of a role of special borders at recrystallization processes in a hot-rolled plate from aluminium alloy of system Al-Si-Mg is the purpose of the present work.

## 2. Materials and methods

Samples of an aluminium alloy AlMg1SiCu (1330) served as research materials. The following sample composition (wt %) was determined by atomic emission analysis: 1.0 Mg, 0.24 Fe, 0.62 Si, 0.14 Zn, 0.1 Mn, 0.19 Cu, 0.06 Cr. The sum of residual impurities is 0.15 wt %. Samples were taken from 23.6 mm thick plates that had been hot-rolled in two different modes [22].

An electron microscope (ZEISS CrossBeam AURIGA) was used to determine the orientation of individual grains and to analyze the local texture (20 kV; Oxford Instruments analysis system; the scanning step – 0.1  $\mu\text{m}$ ). The estimated error limit of the crystal lattice orientation was on average  $\pm 0.6^\circ$ , but did not exceed  $\pm 1^\circ$ . Misorientations from 2 to  $15^\circ$  were marked as small angular boundaries between local volumes. High angles were detected when the misorientation was  $\geq 15^\circ$ .



**Figure 1.** Orientation maps of the surface area aluminum alloy plates (EBSD). (a, b) ND  $\parallel$  Y; (c, d) RD  $\parallel$  X; (a, c) deformed state; (b, d) recrystallized state.

The orientation analysis was performed in laboratory coordinates. The axes of the coordinate system were connected with the normal to its plane (Y  $\parallel$  ND), with hot rolling directions (X  $\parallel$  RD), and perpendicular to their direction (Z  $\parallel$  TD).

## 3. Results and discussion

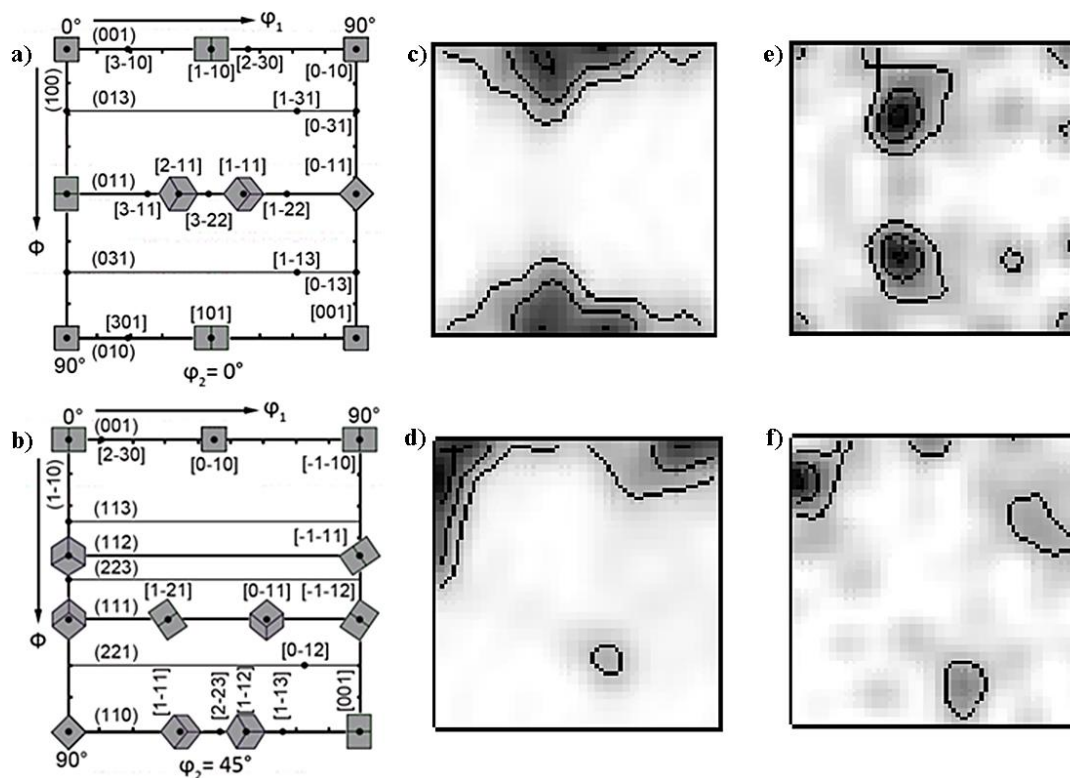
Based on the results of metallographic analysis of specimen structure by thickness depending on the hot rolling mode, it is important to note the following. Based on the results of metallographic analysis of specimen structure by thickness depending on the hot rolling mode, it is important to note the following.

The structure of the sample, which was obtained by deformation mode number 2, consisted of deformed grains stretched in RD (figure 1a, c). Such structure was typical for the entire thickness of the plate.

In the surface layers (up to 1/4 of thickness) of samples from sheets, which were obtained by the rolling regime number 1, the structure consisted mainly of recrystallized grains. The orientation of such grains along the rolled direction was less pronounced (figure 1b, d).

The texture of surface layers at a distance up to about  $\sim 1/4$  of the plate thickness after rolling in deformation state consisted of the set of discrete dispersion orientations: strongly  $\{001\}\langle 320\rangle$ ,  $\{114\}\langle 110\rangle$  and weaker  $\{113\}\langle 110\rangle$ ,  $\{112\}\langle 110\rangle$ ,  $\{223\}\langle 110\rangle$ , (figure 2c, d).

The texture of the surface layers in the recrystallized state consisted of the next set of discrete dispersion orientations: strong  $\{012\}\langle 321\rangle$ ,  $\{114\}\langle 110\rangle$  and weaker  $\{001\}\langle 110\rangle$ ,  $\{113\}\langle 112\rangle$ ,  $\{331\}\langle 123\rangle$ , (figure 2e, f).



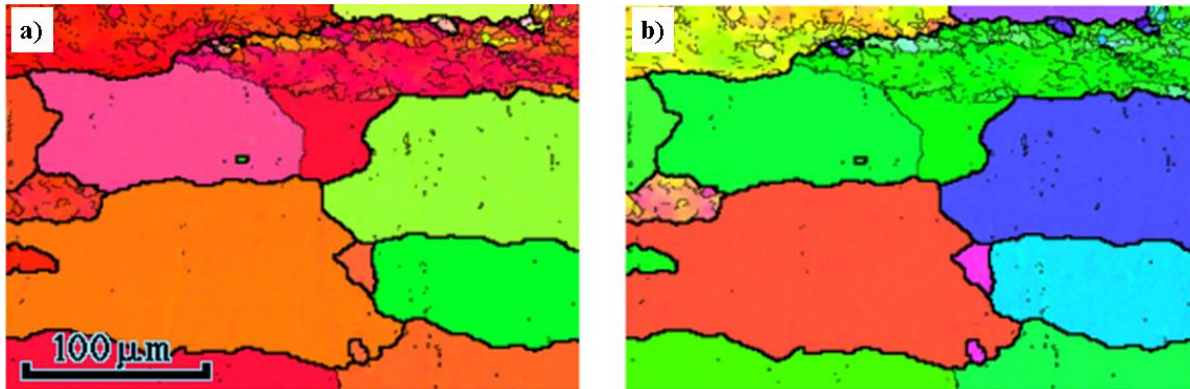
**Figure 2.** Orientation distribution function. The surface of aluminum alloy plates. (a, b) ideal orientations, view from TD; (a, c, e) –  $\phi = 0^\circ$  sections; (b, d, f) –  $\phi = 45^\circ$  sections; (c, d) deformed state; (e, f) recrystallized state.

One may state that in recrystallization caused the growth of grains with orientations that were contained in small quantities in the deformation texture and located at the edges of scattering areas of the main deformation orientations (figure 2). It was often observed that the “carriers” of recrystallization orientations were near-boundary crystallites located inside the deformed grains of one of the main deformation orientations (figure 3).

Vector analysis based on the results of orientation microscopy (EBSD) in the form of Euler angles showed that the grains growing during recrystallization are always in specific misorientation relative to one of the main deformation orientations. This misorientation is formed by turn around one of the crystallographic axes  $\langle 552 \rangle$  at approximately  $52\text{--}53^\circ$ . It is an intermediate misorientation between CSL orientations  $\Sigma 25b$  ( $51.68^\circ$ ,  $\langle 331 \rangle$ ) and  $\Sigma 45c$  ( $53.13^\circ$ ,  $\langle 221 \rangle$ ). EBSD shows both CSL misorientations in the form of CSL boundaries, sometimes transiting into each other between deformed grains and between growing recrystallized and deformed grains as well as in [23]. At the same time, it was



observed [23] that recrystallization nuclei were formed in the deformed grains split by boundaries close to CSL  $\Sigma 3$ . For the deformation texture components, the CSL  $\Sigma 3$  misorientation is observed between the orientations located at the edges of the main dispersion deformation orientations.



**Figure 3.** Orientation maps of local recrystallization (EBSD). (a) from ND || Y; (b) from RD || X.

#### 4. Summary

Thus, the results of this article confirm the results obtained in [23] that the nuclei of recrystallization in an aluminum alloy are crystallites which are with a deformed matrix a high-angle crystallographically ordered border, approximately corresponding to the misorientation: rotation axis  $\langle 552 \rangle$  at an angle of  $52.5^\circ$

#### References

- [1] Wassermann G and Grewen J 1962 *Texturen metallischer Werkstoffe* (Berlin: Springer) p 808
- [2] Hirsch J 2001 *Proc. Int. Conf. on Advances in the metallurgy of aluminum alloys (Indianapolis)* (Novelty: ASM International) p 431
- [3] Engler O, Schafer C and Brinkman H-J 2012 Crystal-plasticity simulation of the correlation of microtexture and roping in AA 6xxx Al–Mg–Si sheet alloys for automotive applications *Acta Materialia* **60** 5217–5232
- [4] Mishra S, Kulkarni K and Gurao N P 2015 Effect of crystallographic texture on precipitation induced anisotropy in an Aluminium magnesium silicon alloy *Materials and Design* **87** 507–519
- [5] Loginov Yu N, Golovnin M A, Lobanov M L and Doroshenko N M 2016 Investigation of the influence of the technology for the production of flat products from the Al–Mg–Si system alloy on the anisotropy of properties *Light alloy technology* **3** 69–74
- [6] Li L, Flores-Johnson E A, Shen L and Proust G 2016 Effects of heat treatment and strain rate on the microstructure and mechanical properties of 6061 Al alloy *International Journal of Damage Mechanics* **25** 26–41
- [7] Shen Y, Garnier J, Allais L, Crepin J, Ancelet O and Hiver J-M 2011 Experimental and numerical characterization of anisotropic damage evolution of forged Al6061 T6 alloy *Procedia Engineering* **10** 3429–3434
- [8] Rusakov G M, Lobanov M L, Redikul'tsev A A and Belyaevskikh A S 2014 Special misorientations and textural heredity in the commercial alloy Fe-3% Si *Physics of Metals and Metallography* **115** 775–785
- [9] Belyaevskikh A S, Lobanov M L, Rusakov G M and Redikul'tsev A A 2015 Improving the production of superthin anisotropic electrical steel *Steel in Translation* **45** 982–986
- [10] Redikul'tsev A A, Rusakov G M and Lobanov M L 2018 The possibility of obtaining electrical steel with texture  $\{100\}\langle 001 \rangle$  *Solid State Phenomena* **284** 483–488
- [11] Vishnyakov Ya D, Babareko A A, Vladimirov S A and Egiz I V 1979 *The theory of texture formation in materials and alloys* (Moscow: Nauka) p 343

- [12] Shtremel' M A 1997 *Strength of alloys. Part II. Deformation* (Moscow: MISiS) p 527
- [13] Schmid E 1924 *Proc. Int. Congress on Applied Mechanics* (Delft: J. Waltman, jr.) p 353
- [14] Sachs G 1928 Zur Ableitung einer Fließbedingung *Zeitschrift des Vereines Deutscher Ingenieure* **72** 734–736
- [15] Taylor G I 1938 Plastic Strain in Metals *Journal of the Institute of Metals* **62** 307–324
- [16] Rollett A, Humphreys F, Rohrer G S and Hatherly M 2004 *Recrystallization and Related Annealing Phenomena: Second Edition* (Oxford: Elsevier) p 574
- [17] Maitland T and Sitzman S 2007 *Electron Backscatter Diffraction (EBSD) Technique and Materials Characterization Examples* (Berlin: Springer) p 522
- [18] Lobanov M L, Yurovskikh A S, Kardonina N I and Rusakov G M 2014 *Methods of investigations material's texture. Work-book* (Ekaterinburg: Ural University Publishers) p 115
- [19] Lobanov M L, Danilov S V, Pastukhov V I, Averin S A, Khrunyk Y Y and Popov A A 2016 The crystallographic relationship of molybdenum textures after hot rolling and recrystallization *Mater. Des.* **109** 251–255
- [20] Lobanov M L, Redikul'tsev A A, Rusakov G M and Danilov S V 2015 Interrelation between the orientations of deformation and recrystallization in hot rolling of anisotropic electrical steel *Met. Sci. Heat Treat.* **57** 492–497
- [21] Redikul'tsev A A, Lobanov M L, Rusakov G M and Lobanova L V 2013 Secondary recrystallization in Fe – 3 % Si alloy with (110)[001] single-component texture *Phys. Met. Metallogr.* **114** 33–40
- [22] Lobanov M L, Loginov Yu N, Danilov S V, Golovin M A and Karabanalov M S 2018 Effect of hot rolling rate on the structure and texture condition of plates of the Al – Si – Mg alloy system *Met. Sci. Heat Treat.* **60** 32–38
- [23] Reznik P, Zorina M and Lobanov M 2019 Role of crystallographic misorientations in the evolution of texture in fcc metals *Mater. Today: Proc.* **19** 187–189

### Acknowledgments

Express our acknowledgements to the program № 211 of the Government of the Russian Federation № 02.A03.21.0006, which is aimed at supporting the leading universities of the Russian Federation.